(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 January 2001 (18.01.2001)

PCT

(10) International Publication Number
WO 01/04662 A1

(51) International Patent Classification⁷: G01V 3/30, E21B 47/01

(21) International Application Number: PCT/US00/15118

(22) International Filing Date: 2 June 2000 (02.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/143,065	9 July 1999 (09.07.1999)	US
60/144,710	20 July 1999 (20.07.1999)	US

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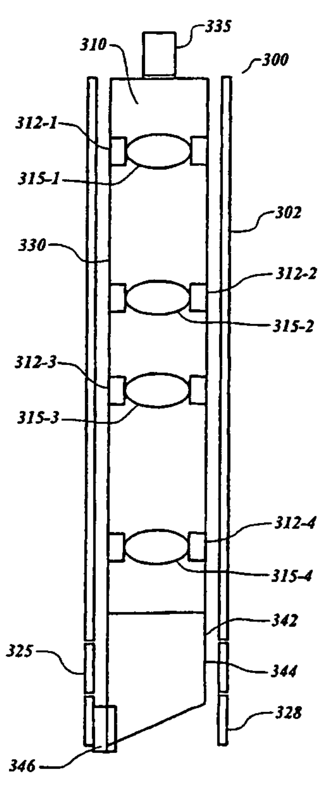
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European

[Continued on next page]

(54) Title: PROPAGATING WAVE EARTH FORMATION RESISTIVITY MEASURING ARRANGEMENT



(57) Abstract: Propagating wave resistivity of a surrounding earth formation is measured by apparatus in a well bore being formed while drilling. The apparatus has a sonde (310) positioned within a drill collar (302) that has its exterior proximate the earth formation during passage of a drill device. The sonde has one or more transmitting antennae (315-1, 315-4) on the housing exterior at first positions that transmit interrogating signals to the earth formation and one or more receiving antennae (315-2, 315-3) that receive signals corresponding to the interrogating signals from the earth formation. The housing (330) has a substantially smooth exterior surface and the antennae are wound in recesses (312-1, 312-2, 312-3, 312-4) in the housing which are filled to be flush with the smooth exterior surface. The drill collar (302) is structured to pass the interrogating signals from the transmitting antennae on the sonde to the earth formation and to pass the signals from the earth formation corresponding to the interrogating signals to the receiving antennae on the sonde.

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patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

PROPAGATING WAVE EARTH FORMATION RESISTIVITY MEASURING ARRANGEMENT

1. Field Of the Invention

The invention relates to measurement of geophysical parameters in earth formations surrounding well bores and, more particularly, to apparatus for measuring the resistivity of earth formations in drilling operations.

2. Background Of the Invention

In oil and gas exploration in which well bores are drilled, the well boring apparatus includes a drill collar to which a drill bit is attached. A drilling fluid is pumped to the drill bit through the drill collar. The drilling fluid exiting from the drill bit is returned to the surface through the space between the exterior of the drill collar and the already drilled portion of well bore.

Resistivity measurements are generally performed in the well bore to determine the characteristics of the surrounding earth formations. These resistivity measurements may be performed by measuring the conduction of electrical current using an arrangement of electrodes within the well bore in a wireline system or using an arrangement of electrodes mounted on a drill collar in a measurement performed while drilling

system. Low frequency induction coils on the drill collar exterior may be used instead of the electrodes. Alternatively, propagating wave resistivity measurements may be performed utilizing transmitting and receiving loop antennas operating at higher frequencies in the range from 400 KHz to 2 MHz. The electronic equipment associated with the electrodes or the loop antennae is housed in a sonde positioned within the drill collar. The sonde has a generally tubular metallic housing and mountings in the housing for electronic equipment used in the measurements. Where electrodes or low frequency loop antennae are used, they are located in recesses on the surface of the drill collar for measurements made while drilling. For the propagating wave resistivity measurements in the 400 KHz to 2 MHz range, one or more pairs of transmitting and receiving antennas may be wound on the exterior of a metal drill collar since the 400 KHz to 2 MHz signals do not propagate through the conductive drill collar.

An exemplary arrangement using antennas mounted on the exterior surface of a drill collar and electronic equipment in a sonde inside the drill collar is disclosed in U.S. Patent 5,892,361 issued April 6, 1999. With the transmitting and receiving antennae on the exterior of the drill collar, the drilling fluid flows in the annulus between the sonde and the interior surface of the drill collar and connections are required between the electronic equipment associated with the

antennae inside the sonde and the antennae on the drill collar exterior. Such connections make it very difficult to retrieve the propagating wave resistivity measuring apparatus from the well bore. Alternatively, the electronic equipment may be mounted in the drill collar itself as disclosed in U.S. Patent 5,402,068 issued March 28, 1995. In the drill collar mounting arrangement, the transmitting and receiving antennae as well as the electronic equipment associated therewith are a part of the drill collar and are not retrievable. The antennae may also be arranged to be proximate to the interior of the drill collar on extensions connected to the sonde so that the drilling fluid flows in the space between the sonde and the antennae. With this structure, it is also very difficult to retrieve the sonde from the well bore.

3. Brief Summary of the Invention

The invention is directed to a propagating wave_resistivity measuring arrangement in a well bore. The measurement arrangement is adapted to determine properties of earth formations surrounding the well bore in which a sonde that houses electronic equipment is positioned in one section of a drill collar structure having plural sections that adjoins the earth formation. The sonde houses devices for processing of signals for the propagating wave resistivity measurements and devices for communicating the results of the propagating

wave resistivity measurements to the surface end of the well bore.

According to the invention, one or more transmitting antennae in the exterior of the sonde housing at first positions generate interrogating signals for transmission to the earth formation surrounding the drill collar and one or more receiving antennae in the exterior of the sonde housing at second positions spaced from first positions receive signals corresponding to the interrogating signals from the earth formation surrounding a first section of drill collar structure. The drill collar passes the interrogating signals from the transmitting antennae on the sonde into the earth formation and passes signals responsive to the interrogating signals from the earth formation to the receiving antennae on the sonde.

According to one aspect of the invention, the exterior surface of the sonde is smooth for laminar drilling fluid flow in the annular passageway between the sonde and the interior surface of the first section of the drill collar structure. Each transmitting antenna is inserted into a recess at a first position on the exterior surface of the sonde and each receiving antenna is inserted into a recess at a second position on the exterior surface of the sonde. The recesses in which the antennae are inserted are filled with a

non-conductive material that is substantially flush with the smooth surface of the housing exterior.

According to another aspect of the invention, a lower end of the sonde is supported in a predetermined position within the drill collar structure on a support in a second section of the drill collar structure located below the first section of the drill collar. The support orients the sonde in a predetermined longitudinal and rotational positions within the drill collar structure.

According to yet another aspect of the invention, the first section of the drill collar structure is made of a material such as a fiber glass epoxy that is transparent to the interrogating signals from the transmitting antennae and to the signals from the earth formation corresponding to the interrogating signals.

According to yet another aspect of the invention, the first section of the drill collar structure is made of a conductive material and includes slotted portions each positioned to provide passage of the interrogating signals from a transmitting antenna to the earth formation and passage of signals from the earth formation corresponding to the interrogating signals to a receiving antenna. The support in the second section of the drill collar structure for the sonde is adapted to position the sonde so that each transmitting antenna radiates interrogating signals through

the slots therein and each receiving antenna receives signals from the earth formation corresponding to the interrogating signals through the slots therein.

According to yet another aspect of the invention, the sonde includes a device at an upper end that receives apparatus for retrieving the sonde from the well bore such as a spear point shaped top section which can be latched with a standard overshot.

In one embodiment illustrative of the invention, a sonde has one or more transmitting antennae in spaced relationship with one or more receiving antennae. The antennae are wound in recesses of a smooth exterior surface of the sonde housing. The recesses are filled with a non-conductive material to be flush with the smooth exterior surface. The sonde is positioned within a non-conductive section of a drill collar structure inserted in a well bore with the lower end of the sonde supported in a predetermined position by a second section of the drill collar structure. Drilling fluid flows down the inside of the drill collar around the smooth exterior surface of the sonde and then, having exited through the drill bit, between the exterior surface of the drill collar and the well bore. The upper end of the sonde has a spear point structure for connection to a wire line to the sonde from the well bore.

In another embodiment illustrative of the invention, a sonde has one or more transmitting antennae in spaced relation to one or more receiving antennae along its length. Each antenna is wound in a recess of a smooth exterior surface of the sonde. The sonde is positioned in a metal section of a drill collar structure inserted into a well bore. The antenna recesses are filled to be flush with the smooth exterior surface and the drill collar has slotted portions positioned along the axis of the sonde aligned with the antennae. The slots are filled with a material transparent to the interrogating signals from the transmitting antennae and to the signals from the earth formation corresponding to the interrogating signals. Processing apparatus associated with the antennae are housed within the sonde. Drilling fluid is pumped down around the sonde within a wash pipe proximate the interior surface of the drill collar and up to the surface of the earth formation around the exterior of the drill collar. The lower end of the sonde is supported in a second section of the drill collar structure in a predetermined position so that the interrogating signals from the transmitting antennae pass through the slots to the surrounding earth formation and the signals from the earth formation corresponding to the interrogating signals pass through the slots to the receiving antennae.

The invention will be better understood from the following more detailed description taken together with the accompanying drawings and the claims.

4. Brief Description of the Drawings

Fig. 1 shows a general diagram of a system for drilling and measuring propagating wave resistivity in an earth formation surrounding a well bore;

Fig. 2 illustrates an arrangement of a sonde in a drill collar structure for propagating wave resistivity measurements while drilling according to the prior art.

Fig. 3 depicts apparatus for propagating resistivity measurement while drilling housed in a sonde within a non-metallic drill collar structure according to one embodiment of the invention;

Fig. 4 depicts apparatus for propagating wave resistivity measurement while drilling housed in a sonde within a metallic drill collar structure according to another embodiment of the invention;

Fig. 5 shows the slot structure of the metallic drill collar structure used in the embodiment of Fig. 4;

Fig. 6 illustrates the arrangement of electronic equipment housed in the sonde in the embodiments of Figs. 3 and 4;

Fig. 7 illustrates a structure that supports the sonde in the drill collar structure of Figs. 3 and 4;

Fig. 8 illustrates an arrangement for retrieving the sonde of the embodiments of Figs. 3 and 4 from the well bore of Fig. 1; and

Fig. 9 shows an alternative drill collar structure for the embodiment of Fig. 4.

5. Detailed Description

Fig. 1 is a schematic diagram showing a well bore 1 being drilled in an earth formation 50 using a drilling rig that includes a derrick 3, a derrick floor 5, a drill string 7, a drill collar 10 and a drill bit structure 28. In drilling, a drilling fluid or "mud" is pumped down through the drill collar 10 by a pump (not shown) and the drill bit structure 28 for drilling. After passing through the drill bit structure, the drilling fluid is returned to the surface of the earth formation 50 between the exterior of the drill collar 10 and the well bore 1.

During the drilling, the propagating wave resistivity of the earth formation 50 surrounding the well bore is measured by apparatus within the drill collar section 10. The measuring apparatus includes spaced apart transmitting antennae radiating interrogating signals in the frequency range of 400 KHz to 2 MHz into the earth formation, spaced apart receiving antennae for receiving signals corresponding to the interrogating signals and processing apparatus that processes the received signals to determine the propagating wave resistivity.

Fig. 2 shows a prior art arrangement of propagating wave resistivity measurement apparatus in a tubular metal drill collar 200. In Fig. 2, a sonde 210 having a tubular housing 230 is shown affixed to and centered in a drill collar 200. Drilling fluid flows in the annular space between the exterior of the sonde and the interior surface of the drill collar. Since the annular space is interrupted by connection/supports 218-1 through 218-4, the drilling fluid flow is somewhat restricted. The metal drill collar 200 has axially positioned circumferential recesses 212-1, 212-2, 212-3 and 212-4. A transmitting loop antenna 215-1 is wound in the recess 212-1 and a transmitting loop antenna 215-4 is wound in the recess 212-4. A receiving loop antenna 215-2 is wound in the recess 212-2 and a receiving loop antenna 215-3 is wound in the recess 212-3.

The transmitting loop antennae 215-1 receives timed signals in the frequency range from 400 KHz to 2 MHz from a transmitter within the housing of the sonde 210 through a connection structure 218-1. The transmitting loop antenna 215-4 receives differently timed signals from another transmitter in the sonde 210 through a connection structure 218-4. The transmitting loop antennae 215-1 and 215-4 operate to transmit differently timed interrogating signals to the surrounding earth formation. Signals responsive to the interrogating signals that are returned from the earth formation to the drill collar 210 are picked up by the receiving antennae 215-2 and 215-3. The returned signals from the receiving antennae are applied to a receiver in the sonde through the connection structures 218-2 and 218-3 and are processed by a processor in the sonde to generate propagating wave resistivity data.

Since the metal drill collar is not transparent to the interrogating and return signals in the frequency range of 400 KHz to 2 MHz, it is necessary to locate the antennae 212-1 to 212-4 on the exterior of the drill collar. It is also necessary to provide connections through the connection structures 218-1 through 218-4 for interrogating signals generated by transmitters within the sonde and for receiving and processing return signals from earth formation in receivers and processors in the sonde. Alternatively, a sonde may not be used and the transmitter, receiver and

processor associated with the transmitting antennae 215-1 and 215-4 and the receiving antennae 215-2 and 215-3 may be mounted on the drill collar itself. In either arrangement, however, the design is relatively complex and expensive and, in addition, the propagating wave resistivity measurement equipment is not retrievable independent of the drill collar.

Fig. 3 depicts a sonde in a non-conducting drill collar for a propagating wave resistivity measurement according to one embodiment of the invention. Referring to Fig. 3, there is schematically shown a drill collar structure 300, a non-conductive measuring section 302 of drill collar structure 300, a sonde 310 in the drill collar structure section 302, recesses 312-1, 312-2, 312-3 and 312-4, loop antennae 315-1, 315-2, 315-3 and 315-4, a pony section 325 of the drill collar structure 300, a landing sub section 328 of the drill collar structure 300 and an attachment structure 335. The transmitting and receiving antennae of the sonde 310 are positioned in the measurement section 302, the landing sub section 328 has a muleshoe device 344 and the pony section 325 connects the measuring section 302 and the landing sub section 328. The drill collar measuring section 302 may be made of any suitable non-conducting material such as fiberglass reinforced epoxy. In order to protect the drill collar section 302 from rapid wear, wear rings containing tungsten carbide may be inserted or the drill collar section

302 may be coated overall with a hard material such as a ceramic.

A housing 330 of the sonde 310 in Fig. 3 may be made of stainless steel or beryllium copper. The housing 330 has a general shape of a right circular cylinder with a smooth outer surface. Circumferential recesses 312-1 through 312-4 that are spaced along the axis of the sonde are formed in the outer surface of the housing. A first transmitting loop antenna 315-1 is wound in the recess 312-1 and a second transmitting loop antenna 315-4 is wound in the recess 312-4. A first receiving loop antenna 315-2 is wound in the recess 312-2 and a second receiving antenna 315-3 is wound in the recess 312-3. After the antenna 315-1 through 315-4 are wound, the recesses 312-1 through 312-4 are filled with a material such as Viton rubber and the surfaces of the filled recesses are made substantially flush with the smooth surface of the housing 330. The lower end of the sonde is supported on a support structure in a landing sub section 328 which is connected to the section 302 by a pony section 325.

Fig. 7 is a schematic diagram showing one arrangement to detachably support the sonde 310 on the drill collar 300 of Fig. 3 so that the sonde can be lifted from the drill collar and retrieved from the well bore. In Fig. 7, there is shown the pony section 325 and the landing sub section 328. The pony section 325 is threadedly attached to the measuring

section 302 of the drill collar and the landing sub section 328 is threadedly attached to the pony section 325. The interior surface of the landing sub section 328 has a "muleshoe" sleeve 344 which detachably supports an orienting sleeve 342 of the lower end of the sonde 310 so that the sonde is longitudinally oriented. A muleshoe pin 346 of the landing sub section fits into the orienting sleeve 342 of the lower end of the sonde 310 to rotationally orient the sonde.

Since the sonde 310 is detachably supported by the landing sub arrangement but is not affixed to the drill collar 300, the sonde may be retrieved from the drill collar by lifting it upward in the well bore using a wire line connection to the attachment structure 335 shown in Fig. 3. The attachment structure may be a spear point formed at the upper end of the sonde 310 as shown in Fig. 8. The spear point end 537 of the upper sonde portion shown in Fig. 8 is positioned in the center of the drill collar 310 as determined by the sonde support structure in the landing sub section 328. In retrieving the sonde 310 from the drill collar 300, a standard overshot device connected to a wire line is latched onto the spear point and the sonde is raised in the well bore 1. It is to be understood that structures other than a muleshoe and a spear point and overshoot device may be employed to support the sonde and to retrieve the sonde from the well bore.

The drill collar 300 is made of a non-conductive material that is transparent to the interrogating signals from the transmitting antennae 315-1 and 315-4 and is also transparent to the responsive return signals from the earth formation surrounding the drill collar. The electronic equipment associated with the transmitting and receiving antennae 315-1 through 315-4 is located within the sonde housing and is directly coupled to the antennae. Accordingly, there is no restriction to drilling fluid flow from the electromechanical connections between the sonde and the adjacent drill collar. Since the entire propagating wave resistivity system is located in the sonde and the sonde is not affixed to the drill collar, the sonde may be readily retrieved from the well bore as disclosed with respect to Fig. 8.

Fig. 4 depicts another embodiment of the invention in which the sonde is supported in a predetermined position within a drill collar structure. Shown in Fig. 4 is a drill collar 400 having a metal drill collar measurement section 402, a wash pipe 405 and a sonde 410. The sonde has recesses 412-1, 412-2, 412-3 and 412-4 into which loop antennae 415-1, 415-2, 415-3 and 415-4 are wound, a lower end orienting sleeve 442 and an upper end attachment section 435. The loop antennae 415-1, 415-2, 415-3 and 415-4 is positioned in the drill collar structure measurement section 402 and has slotted portions 421-1, 421-2, 421-3 and 421-4 aligned with the loop antennae. A landing sub section 428 of the drill collar

includes a structure for detachably supporting the lower end of the sonde and a pony section 425 connects the measuring section 402 and the landing sub section 428.

A housing 430 of the sonde 410 has a smooth exterior surface. The circumferential recesses in the housing 430 are spaced along the length of the sonde. A first transmitting loop antenna 415-1 is wound in the recess 412-1 and a second transmitting loop antenna 415-4 is wound in the recess 412-4. A first receiving antenna 415-2 is wound in the recess 412-2 and a second receiving antenna 415-3 is wound in the recess 412-3. After winding of the antennae therein, the recesses are filled with a non-conductive material such as Viton rubber and the surfaces of the recesses are made substantially flush with the smooth surface of the housing 430.

The lower end of the sonde is supported on a landing sub section 428 which is arranged to position the sonde longitudinally and rotationally. The supporting structure is substantially the same as that described with respect to Fig. 7 in which an orienting sleeve 442 is detachably supported by a muleshoe 444. The muleshoe 444 orients the sonde 410 longitudinally and a muleshoe pin 446 orients the sonde rotationally. The top end of the sonde includes an attachment unit 435 such as a spear point adapted to be

connected to a wire from the derrick 3 for retrieving the sonde from the well bore.

When the sonde 410 is in a supported position on the landing sub section 428, the sonde is positioned so that the transmitting loop antennae 415-1 and 415-4 are aligned with slots of slotted portions 421-1 and 421-4, respectively, of the measuring portion 402 of the drill collar structure and the receiving loop antennae 415-2 and 415-3 are aligned with slots of slotted portions 421-2 and 421-3, respectively, of the measuring portion 402 of the drill collar structure. Drilling fluid flowing around the sonde 410 in the drill collar 400 is contained within a wash pipe 405 in the slotted drill collar measuring section 402. The wash pipe 405 is proximate the interior surface of the drill collar section 402. The exterior surface of the wash pipe 405 is sealed to the interior surface of the drill collar at a point above the uppermost set of slots by an O ring 439 or other sealing device and at a point below the lowermost set of slots by an O ring 440. It is to be understood that other sealing arrangements may be used in Fig. 4. Each of the slots of the slotted portions 421-1 through 421-4 is preferably filled with a non-conductive material that is transparent to the interrogating signals from the transmitting loop antennae 415-1 and 415-4 and to the return signals from the surrounding earth formation. The sealing of the exterior of the wash pipe to the interior of the drill collar prevents

the highly pressurized drilling fluid flowing inside the wash pipe 405 from exiting through the slotted portions of the sonde.

Fig. 5 illustrates the slot structures in the drill collar section 402 of Fig. 4. Referring to Fig. 5, in which a set of slots of slotted portion 421-1 in the drill collar structure section 402 is located at one end to be aligned with the transmitting loop antenna 415-1 when lower end of the sonde 410 is supported in the landing sub section 428 of the drill collar structure. A set of slots of the slotted portion 421-4 is located at the lower end of the drill collar section 402 for alignment with the transmitting loop antenna 415-4. A set of slots of the slotted portion 421-2 in the drill collar is located on the sonde 410 to be aligned with the receiving antenna 415-2 and a set of slots of the slotted portion 412-3 is located on the sonde for alignment with the receiving antenna 415-3.

The drill collar structure section 402 of Fig. 4 may also be constructed as shown in Fig. 9 to have fiber-glass epoxy composite sections aligned with the transmitting antennae and the receiving antennae wound on the sonde 410. Referring to Fig. 9, the propagating resistivity measuring section 402 of the drill collar structure 400 has generally cylindrical metal sections 930-1, 930-2, 930-3, 930-4 and 930-5. A generally cylindrical fiber-glass epoxy composite section

923-1 is secured between the metal sections 930-1 and 930-2 and is aligned with the transmitting antenna 415-1 for passage of interrogating signals therethrough to the surrounding earth formation. Similarly, a cylindrical fiber-glass composite section 923-4 between the metal sections 930-4 and 930-5 is aligned with the transmitting antenna 415-4 for passage of interrogating signals therethrough. A cylindrical fiber-glass composite section 923-2 between metal sections 930-2 and 930-3 aligned with the receiving antenna 415-2 allows passage of return signals from the earth formation to the antenna 415-2. In like manner, a cylindrical fiber-glass section 923-3 between metal sections 930-3 and 930-4 is aligned with receiving antenna 415-3 to permit passage of return signals from the earth formation to the antenna 415-3. The alternating metal and fiber-glass composite sections of the same diameter of Fig. 9 may be threadedly connected to form the drill collar structure section 402. It is to be understood that other arrangements of interrogating and return signal transparent materials may be used to assure passage of these signals between the sonde 410 and the surrounding earth formation. For example, a single fiber-glass composite section may be aligned with both receiving antennae 414-2 and 415-3.

The electronic equipment associated with the transmitting and receiving loop antennae 415-1 through 415-4 is located in the sonde housing 430 and is connected directly to the antennae.

As discussed with respect to the embodiment shown in Fig. 3, the sonde 410 is readily detachable from the drilling collar 400. Accordingly, a wire from the derrick 3 may be lowered into the well bore and connected to the sonde attachment unit 435 so that the sonde may be retrieved from its supported position in the drill collar 400. As shown in Fig. 8 and disclosed with respect to the embodiment of Fig. 3, the sonde 410 may have a spear point end 537 for connection with a wire line so that the sonde may be lifted off the support structure in the landing sub section 428 and retrieved from the well bore.

Fig. 6 shows electronic equipment located inside the housing 330 of the sonde 310 of Fig. 3 or inside the housing 430 of the sonde 410 of Fig. 4. The electronic equipment includes a control 601, an upper transmitter 610 and a lower transmitter 615, an upper receiver 620 and a lower receiver 625, a propagating wave resistivity signal processor 630 and a data transmitting device 635 such as a mud pulser, an EM telemetry device or other arrangement well known in the art. The control 601 controls the operations of the transmitters, the receivers and the signal processor. The upper transmitter 610 provides an interrogating signal in the range of 400 KHz to 2 MHz and controls the timing of the operation of transmitting antenna 315-1 or 415-1. The lower transmitter 615 provides an interrogating signal in the range of 400 KHz to 2 MHz and controls the timing of the operation of the

transmitting antenna 315-4 or 415-4. Upper and lower receivers 620 and 625 receive signals from the earth formation returned to antennae 315-2 and 315-3 or 415-2 and 415-3 in response to the interrogating signals. Signal processor 630 processes the return signals from the receivers to generate amplitude ratio and phase difference signals corresponding to the propagating wave resistivity. The coded signals corresponding to the propagating wave resistivity are transmitted to the surface by the data transmitting device 635 so that coded signals are picked up at the top of the well bore.

In operation, upper and lower transmitters 610 and 615 sequentially send interrogating signals to antennae 315-1 and 315-4 or 415-1 and 415-4. Receivers 620 and 625 operate to receive return signals in response to each of the sequential interrogating signals. The outputs of receivers 620 and 625 are processed in propagating wave resistivity signal processor 630 as is well known in the art to determine propagating wave resistivity of the earth formation surrounding the drill collar responsive to the return signals. The output of the propagating wave resistivity processor 630 is applied to the data transmitter 635 and is communicated to the top of the well bore.

While the invention has been described by way of particular illustrative embodiments, it is to be understood that the

invention is not limited to the above-described embodiments but that various changes and modifications may be made by those of ordinary skill in the art without departing from the scope and spirit of the invention. Accordingly, the foregoing embodiments should not be construed as limiting the scope of the invention which is encompassed instead by the following claims.

6. What is claimed is:

1. Apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device comprising:

a hollow drill collar structure having plural sections with an exterior proximate to the earth formation during passage of the drill device into the well bore; and

a sonde within the drill collar structure including:

a housing;

one or more one transmitting antennae wound at first positions in an exterior surface of the housing positioned within a first section of the drill collar structure for transmitting interrogating signals to the earth formation; and

one or more receiving antennae wound at second positions in the exterior surface of the housing spaced from the first positions and positioned in the first section of the drill collar structure for receiving signals from the earth formation in response to the interrogating signals;

wherein the first section of the drill collar structure passes the interrogating signals from the transmitting antennae on the sonde through to the earth formation surrounding the well bore and passes the signals responsive to the interrogating signals from the earth

formation surrounding the well bore through to the receiving antennae on the sonde.

2. The apparatus of Claim 1, wherein the exterior surface of the housing of the sonde is substantially smooth and includes a recess in which each transmitting antenna is wound and a recess in which each receiving antenna is wound, the recesses with the wound antennae being filled with a non-conductive material with an outer surface that is substantially flush with the substantially smooth exterior surface of the housing.

3. The apparatus of Claim 1, wherein the drill collar structure includes a second section which comprises a structure for supporting a lower end of the sonde.

4. The apparatus of Claim 3, wherein the structure for supporting the lower end of sonde in the second section of the drill collar structure contacts a lower end of the sonde to position the sonde in the drill collar structure.

5. The apparatus of Claim 1, wherein the drill collar structure first section is transparent to the interrogating signals from the transmitting antennae and is transparent to the signals from the earth formation corresponding to the interrogating signals.

6. The apparatus of Claim 5, wherein the drill collar first section is made of a fiberglass epoxy.

7. The apparatus of Claim 1, wherein the drill collar structure first section is made of a conductive material and includes one or more slotted portions each positioned to provide passage of the interrogating signals from a transmitting antenna to the earth formation and one or more slotted portions each positioned to provide passage of signals from the earth formation corresponding to the interrogating signals to the receiving antenna.

8. The apparatus of Claim 7, wherein the slots of each slotted portion are filled with a material transparent to the interrogating signals from the transmitting antennae and to the signals from the earth formation corresponding to the interrogating signals.

9. The apparatus of Claim 7, wherein the drill collar structure includes a second section comprising a support for supporting the sonde in a position so that each transmitting antenna radiates interrogating signals through slots of one of the slotted portions of the drill collar structure first section and each receiving antenna receives signals from the earth formation corresponding to the

interrogating signals through slots of one of the slotted portions of the drill collar structure first section.

10. The apparatus of Claim 1, wherein the sonde further comprises a structure for receiving a retrieving unit thereto.

11. The apparatus of Claim 10, wherein the structure for receiving a retrieving unit to the sonde includes a unit at an upper end of the sonde for attaching a retrieving wire thereto.

12. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure with plural sections comprising:

a housing positioned in the drill collar structure;

one or more one transmitting antennae wound at first positions in an exterior surface of the housing positioned in a first section of the drill collar structure for transmitting interrogating signals to the earth formation;

one or more receiving antennae wound at second positions in the exterior surface of the housing spaced from the first positions and positioned in the first section of

the drill collar structure for receiving signals from the earth formation in response to the interrogating signals;

wherein the first section of drill collar drill collar structure passes the interrogating signals from the one or more transmitting antennae on the sonde through to the earth formation surrounding the well bore and passes the signals corresponding to the interrogating signals from the earth formation surrounding the well bore pass to the receiving antenna on the sonde.

13. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 12, wherein the exterior surface of the sonde housing is substantially smooth and includes a recess into which each transmitting antenna is wound and a recess into which each receiving antenna is wound, the recesses with the wound antennae being filled with a non-conductive material with an outer surface substantially flush with the substantially smooth exterior surface of the housing.

14. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 12, wherein the drill collar structure includes a support for supporting a lower end of the sonde.

15. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 14, wherein the support for supporting the lower end of the sonde in the drill collar contacts the lower end of the sonde.

16. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 12, wherein the first section of the drill collar structure is transparent to the interrogating signals from the transmitting antennae and is transparent to the signals from the earth formation corresponding to the interrogating signals.

17. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 16, wherein the material of the drill collar structure first section is a fiber glass epoxy.

18. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 12, wherein the first section of the drill collar structure is made of a conductive material and includes one

or more slotted portions each positioned to provide passage of the interrogating signals from the transmitting antenna to the earth formation and passage of signals from the earth formation corresponding to the interrogating signals to the receiving antenna.

19. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 18, wherein slots of each slotted portion are filled with a material transparent to the interrogating signals from the transmitting antennae and transparent to the signals from the earth formation corresponding to the interrogating signals.

20. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 18, wherein a second section of the drill collar structure includes a support for supporting the sonde so that each transmitting antenna radiates interrogating signals through slots of one of the slotted portions and each receiving antenna receives signals from the earth formation corresponding to the interrogating signals through the slots of one of the slotted portions.

21. A sonde in apparatus for measuring

parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 12, wherein the sonde further comprises a structure for receiving a retrieving unit.

22. A sonde in apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a drill collar structure according to Claim 21, wherein the structure for receiving a retrieving unit includes a spear point unit at an upper end of the sonde for attaching a retrieving wire thereto.

23. A method for measuring parameters of an earth formation surrounding a well bore being formed by a drill device having a sonde in a drill collar structure having plural sections, the sonde having one or more transmitting antennae wound at axially spaced first positions in an exterior surface of a housing of the sonde positioned in a first section of the drill collar structure for propagating interrogation signals to the earth formation surrounding the drill collar and one or more receiving antennae wound at axially spaced second positions in the exterior surface of the sonde housing positioned in the first section of the drill collar structure for receiving signals corresponding to the interrogating signals from the earth formation surrounding the drill collar, method comprising the steps of:

passing the interrogating signals from the

transmitting antennae on the sonde housing through the drill collar to the earth formation surrounding the drill collar; and

passing the signals corresponding to the interrogating signals from the surrounding earth formation through the drill collar to the receiving antenna on the sonde housing.

24. The method of Claim 23, wherein the exterior surface of the housing is substantially smooth, each transmitting antenna and receiving antenna is wound in a recess in the exterior surface of the housing and the recesses having the wound antennae are filled with a non-conductive material having an outer surface that is substantially flush with the substantially smooth exterior surface of the housing.

25. The method of Claim 23, wherein a second section of the drill collar structure includes a support for detachably supporting a lower end of the sonde.

26. The method of Claim 25, wherein the support in the second section of the drill collar contacts the lower end of the sonde.

27. The method of Claim 23, wherein the first section of the drill collar is made of a material

transparent to the interrogating signals from the transmitting antenna on the sonde and is transparent to the signals from the earth formation corresponding to the interrogating signals.

28. The method of Claim 27, wherein the material of the drill collar is a fiber glass epoxy.

29. The method of Claim 23, wherein the first section of the drill collar structure is made of a conductive material and includes one or more slotted portions each positioned to provide passage of the interrogating signals from a transmitting antenna on the sonde to the earth formation and passage of signals from the earth formation corresponding to the interrogating signals to the receiving antenna.

30. The method of Claim 29, wherein slots of each slotted portion are filled with a material transparent to the interrogating signals from the transmitting antennae and transparent to the signals from the earth formation corresponding to the interrogating signals.

31. The method of Claim 29, wherein the second section of the drill collar structure supports the sonde so that each transmitting antenna radiates the interrogating signals through slots of one of the slotted

portions and each receiving antenna receives signals from the earth formation corresponding to the interrogating signals through the slots of one of the slotted portions.

32. The method of Claim 23, wherein the sonde receives a unit for retrieving the sonde from the well bore.

33. The method of Claim 32, wherein the receiving unit of the sonde receives the retrieving unit by attaching a retrieving wire to a spear point at a top end of the sonde.

34. Apparatus for measuring propagating resistivity of an earth formation surrounding a well bore being drilled comprising:

a drill collar having plural tubular sections adjacent to the well bore during passage of a drill bit into the well bore; and

a sonde positioned in the drill collar structure including:

a generally cylindrical housing having an exterior surface with a set of spaced circumferential recesses therein, the recesses being positioned in a first section of the drill collar structure;

first and second loop antennae each wound in one of the circumferential recesses for transmitting interrogating signals to the surrounding earth formation;

third and fourth loop antennae each one wound in one of the circumferential recesses for receiving signals corresponding to the interrogating signals from the surrounding earth formation,

wherein the first section of drill collar structure passes the interrogating signals from the transmitting loop antenna on the sonde to the earth formation surrounding the well bore and passes the signals responsive to the interrogating signals from the earth formation surrounding the well bore through to the receiving antenna on the sonde,

wherein the exterior surface of the sonde housing is substantially smooth and each loop antenna recess is filled with a non-conductive material flush with the substantially smooth exterior surface, and

wherein a second section of the drill collar lower than the first section includes a support for detachably supporting a lower end of the sonde so that the sonde is retrievable from the well bore.

35. The apparatus of Claim 34, wherein the first section of the drill collar is transparent to the interrogating signals from the transmitting loop antennae and is transparent to the signals from the surrounding earth formation corresponding to the interrogating signals.

36. The apparatus of Claim 34, wherein the first section of the drill collar is made of a conductive material and includes a set of slots aligned with each of the circumferential recesses in the sonde for passing interrogating signals from the transmitting loop antennae to the surrounding earth formation and for passing signals from the earth formation to the receiving loop antennae corresponding to the interrogating signals.

37. Apparatus for measuring characteristics of an earth formation surrounding a well bore comprising:

drill collar means having plural sections proximate the earth formation;

means for measuring propagating wave resistivity of the surrounding earth formation including:

housing means within the drill collar means;

circumferential recesses in the exterior surface of the housing in a first section of the drill collar means;

transmitting means in one or more of the circumferential recesses for transmitting interrogating signals to the surrounding earth formation;

receiving means in one or more of the circumferential recesses for receiving signals from the surrounding earth formation corresponding to the interrogating signals,

wherein the first section of the drill collar means passes the interrogating signals from the transmitting means to the surrounding earth formation and passes the signals corresponding to the interrogating signals from the surrounding earth formation to the receiving means.

38. The apparatus of Claim 37, wherein an exterior surface of the housing means is subtantially smooth and the circumferential recesses are filled to be substantially flush with the exterior surface of the sonde housing.

39. The apparatus of Claim 37, wherein the drill collar means includes a second section including support means for supporting a lower end of the housing means so that the sonde can be lifted up the well bore.

40. The apparatus of Claim 39, wherein the drill collar means first section includes plural slotted portions for providing passage of the interrogating signals from the one or more transmitting means to the earth formation and passage of signals corresponding to the interrogating signals from the earth formation to the one or more receiving means when the lower end of the housing means is supported on the drill collar means.

41. The apparatus of Claim 37, wherein the first section of the drill collar means is transparent to the interrogating signals from the transmitting means and is transparent to the signals corresponding to the interrogating signals from the surrounding earth formation.

42. The apparatus of Claim 37 wherein the housing means further comprises means for connecting to a unit for retrieving the propagating wave resistivity measuring means from the well bore.

43. Apparatus for measuring parameters of an earth formation surrounding a well bore being formed by a drill device comprising:

a hollow drill collar having plural sections with an exterior proximate to the earth formation during passage of the drill device into the well bore; and

a sonde within the drill collar structure including:

a housing;

one or more one transmitting antennae wound at first positions in an exterior surface of the housing positioned within the first section of the drill collar structure for transmitting interrogating signals to the earth formation;

one or more receiving antennae wound at second positions in the exterior surface of the housing

spaced from the first positions and positioned in the first section of the drill collar structure for receiving signals from the earth formation in response to the interrogating signals;

wherein a second section of the drill collar structure includes a support for detachably supporting a lower end of the sonde so that the sonde is retrievable from the well bore.

44. Apparatus according to Claim 43, wherein the support in second section of the drill collar structure for detachably supporting the lower end of the sonde includes a structure that contacts the lower end of the sonde.

45. Apparatus according to Claim 44, wherein the sonde further includes a structure at an upper end for receiving a device to retrieve the sonde from the well bore.

46. The apparatus of Claim 45, wherein the structure for receiving a retrieval device includes a spear point at an upper end of the sonde for receiving an overshot device.

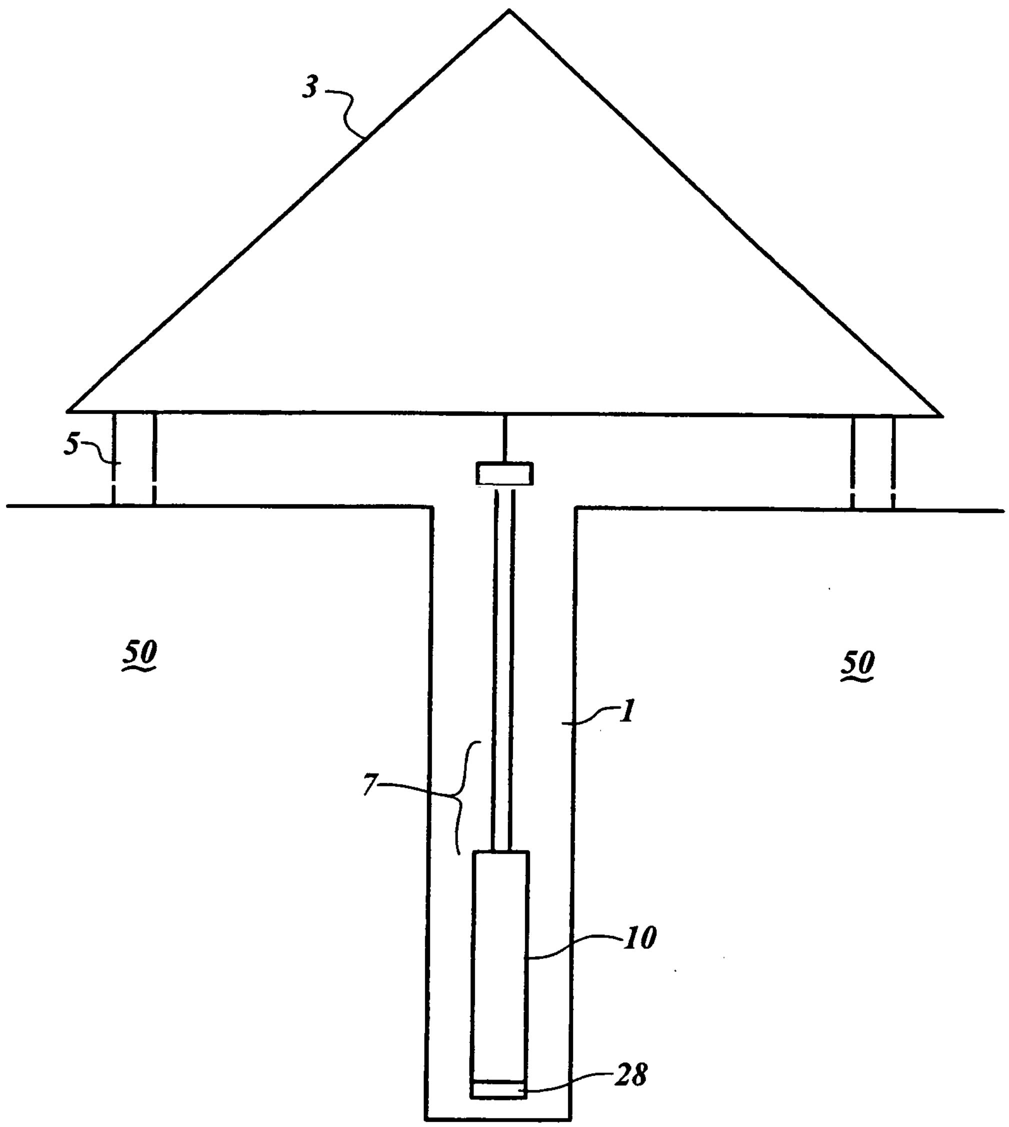

Fig.1

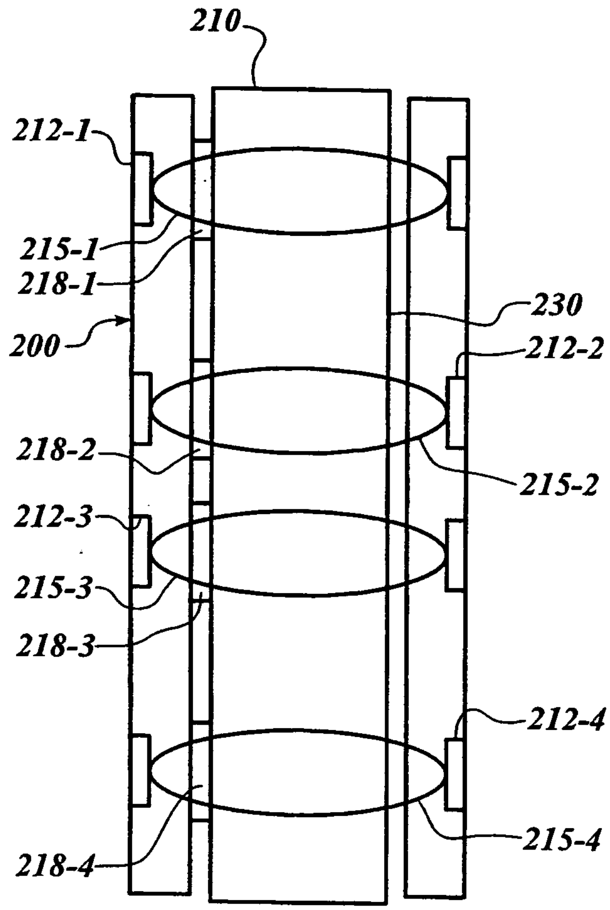
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Fig.2

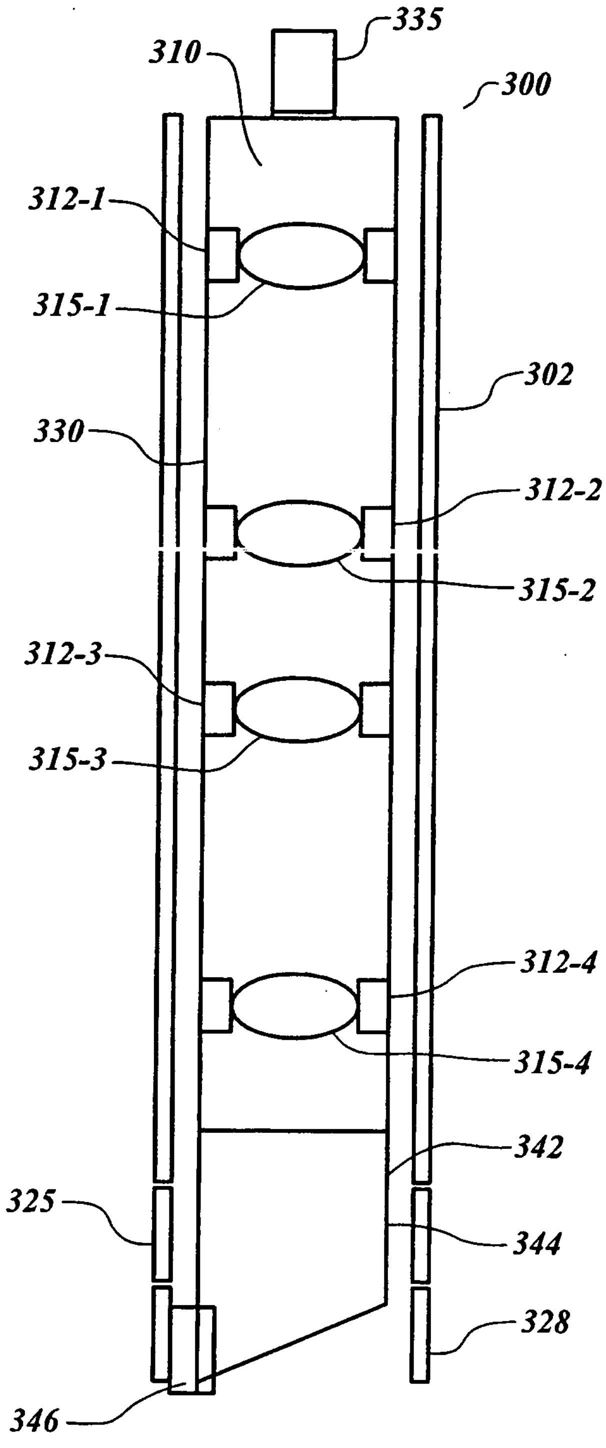
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Fig.3

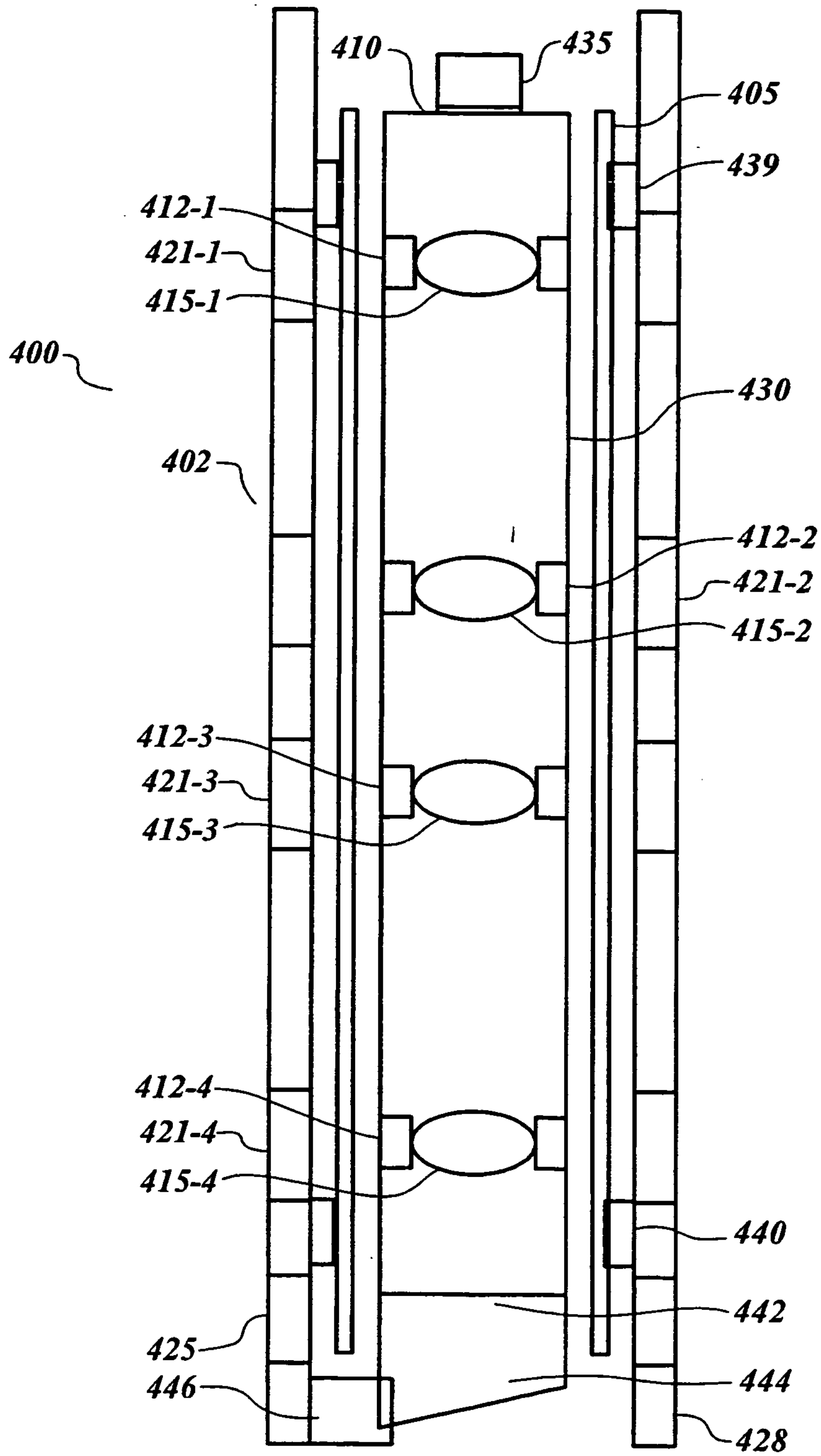

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Fig. 4

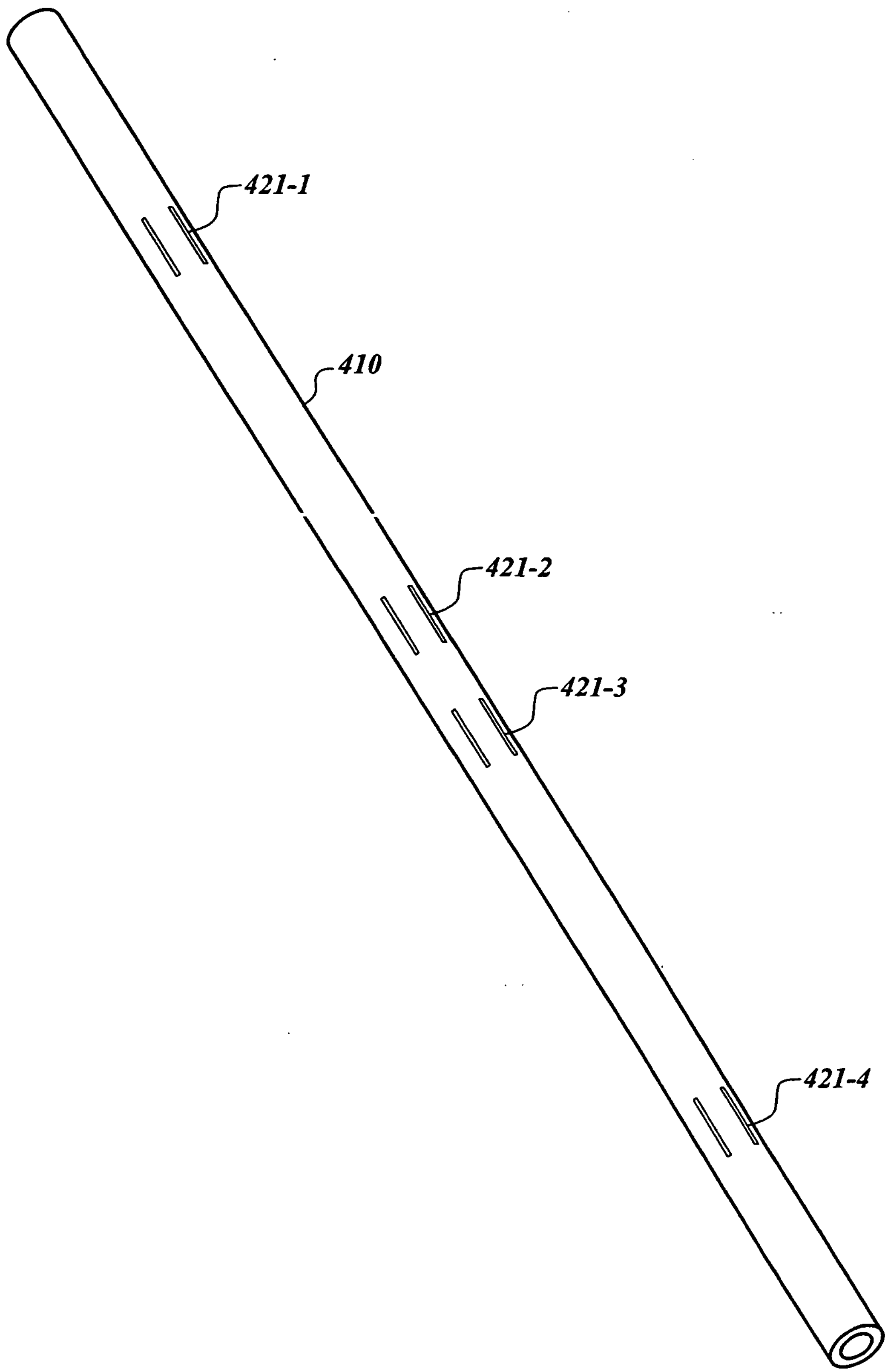
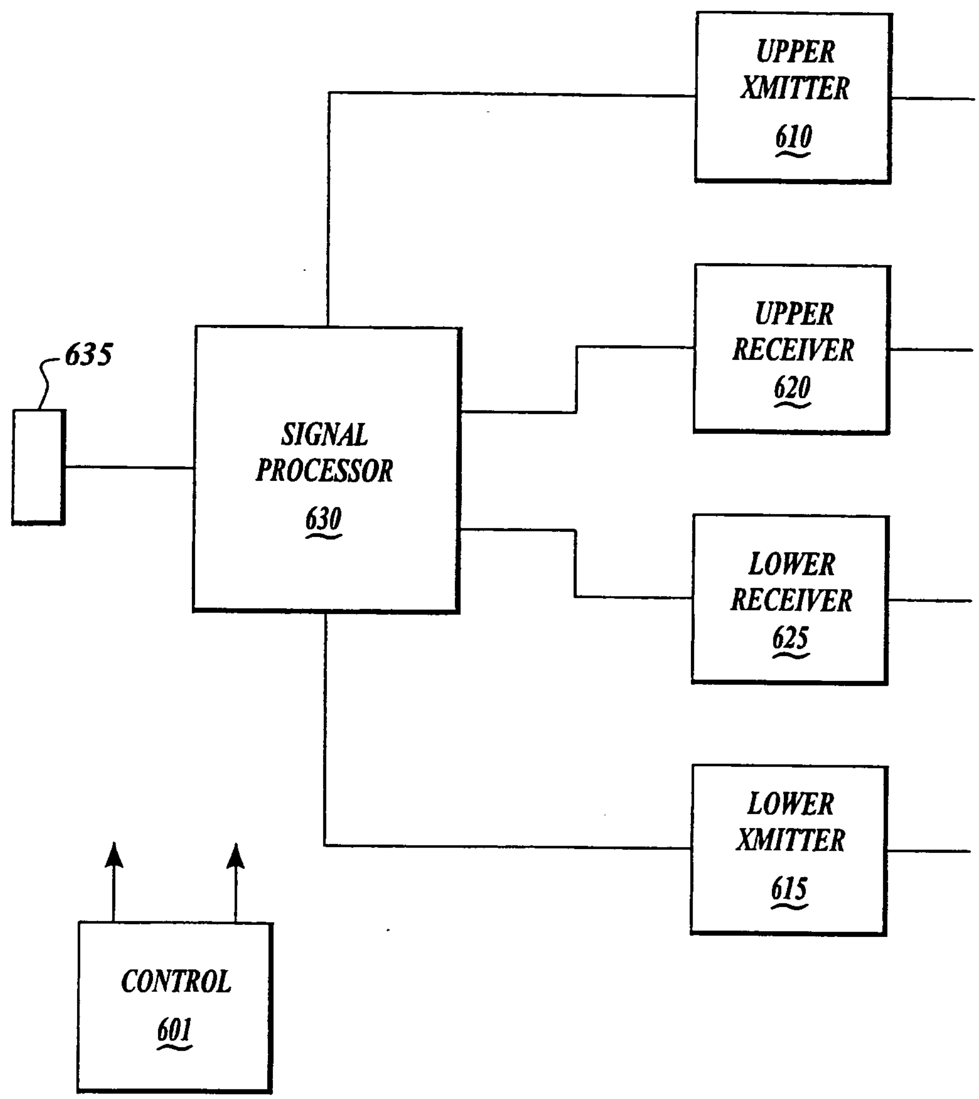


Fig. 5



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UPPER RECEIVER 620
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SIGNAL PROCESSOR 630
LOWER RECEIVER 625
LOWER XMITTER 615
CONTROL 601

Fig. 6

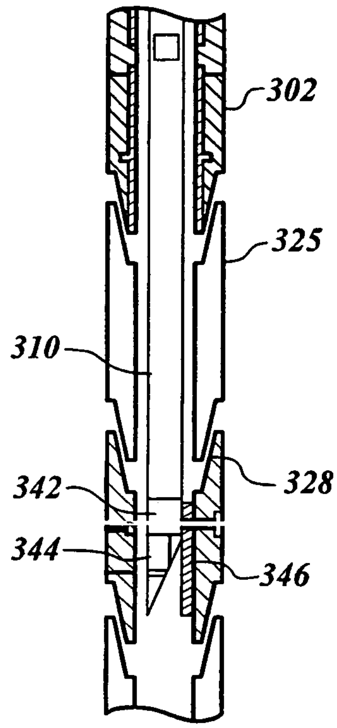

Fig. 7

Fig. 8

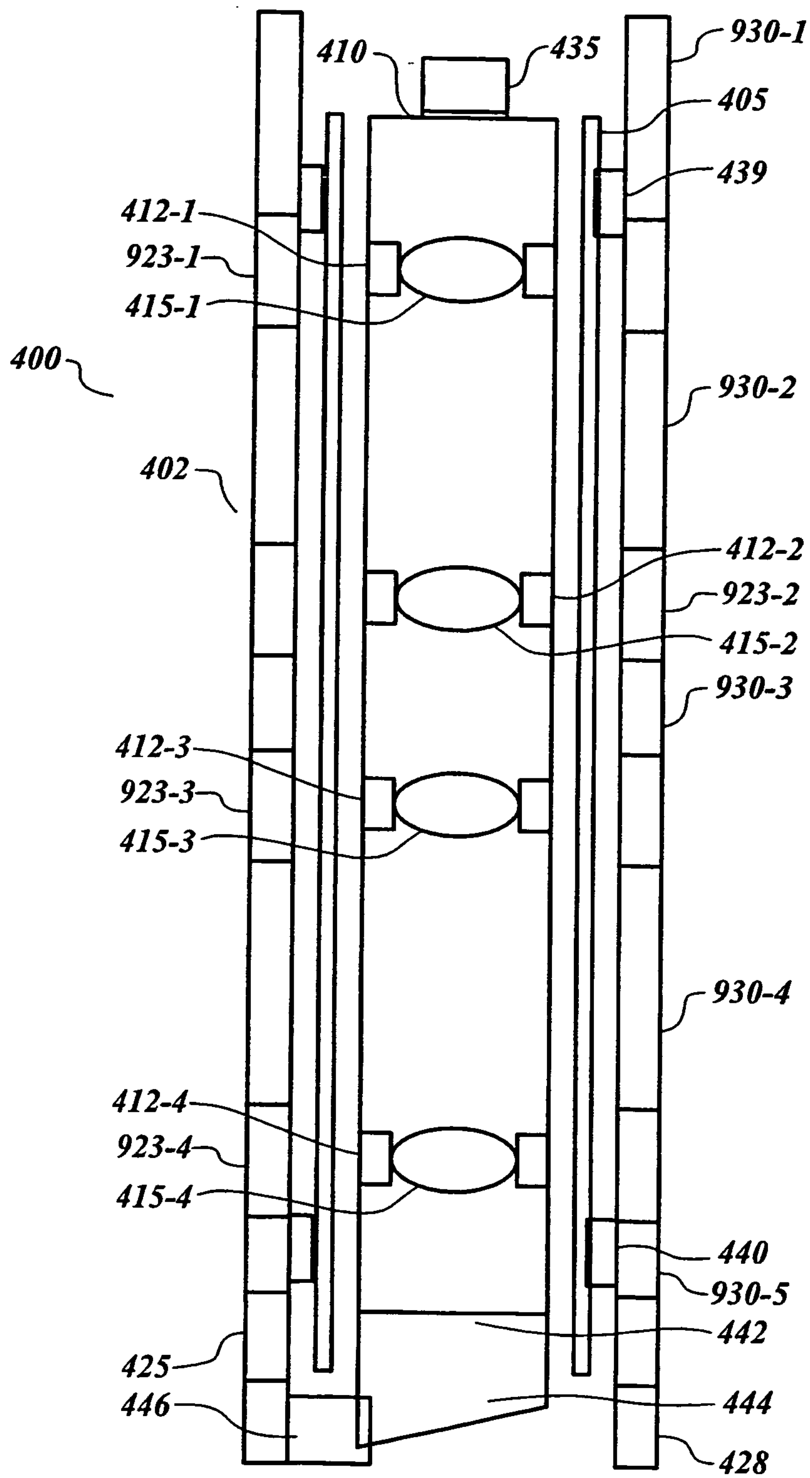

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Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/15118

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01V3/30 E21B47/01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01V E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 704 717 A (BAKER HUGHES INC) 3 April 1996 (1996-04-03)	1,2,5,7, 8,12,13, 16,18, 19,23, 24,27, 29,30, 37,38,41
A	page 9, line 46 -page 10, line 30; figures 3A,3B	34,43
X	EP 0 778 474 A (INTEGRATED DRILLING SERV LTD ;BAFCO INTERNATIONAL COMPANY IN (US)) 11 June 1997 (1997-06-11)	1,2,5,7, 12,13, 16,18, 23,24, 27,29, 37,38,41
A	column 3, line 45 -column 4, line 32	34,43

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search	Date of mailing of the international search report
25 September 2000	05/10/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/US 00/15118

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication where appropriate, of the relevant passages	Relevant to claim No.
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P,A	column 7, line 16 -column 8, line 14; figures 1,2	34,37,43
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INTERNATIONAL SEARCH REPORT

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International Application No
PCT/US 00/15118

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